



**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460**

**OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD**

EPA-SAB-20-xxx

The Honorable Andrew Wheeler
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Transmittal of the Science Advisory Board Report on its technical review of EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19, dated [TBD].

Dear Administrator Wheeler,

Please find enclosed the final report from the Scientific Advisory Board (SAB). The EPA's Office of Research and Development (ORD) requested that the SAB review the document: EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19.

In response to the EPA's request, the SAB assembled the SAB COVID-19 Review Panel with subject matter experts to provide rapid advice on opportunities for current and future EPA research activities that might enhance and inform EPA's current and any future responses to SARS-CoV-2. The SAB COVID-19 Review Panel met by teleconference on April 30, 2020 to deliberate on the charge questions. Written public comments were considered throughout the advisory process. This report conveys the consensus advice of the SAB.

Overall, the SAB commends the Agency on its development of a compendium summarizing current understanding and capabilities related to SARS-CoV-2. The SAB largely agrees with the current and future EPA research ideas and includes several recommendations within this report, including the following highlights.

Paramount to EPA's research efforts is the identification of an infectious dose of SARS-CoV-2, along with the development of techniques to sample and analyze virus viability on various matrixes and settings. These considerations are pivotal to SAB's research recommendations, which include: the formulation of a conceptual model; the characterization of the long-term disinfection properties of various agents (e.g., nano-silver or nano-copper products); the characterization of the environmental persistence of the viable virus on air, water, and surfaces (e.g., aerosols, particulate matter, surface/wastewaters, plastics, metals, fabrics, among others);

the investigation of factors to reduce the virus viability in indoor and outdoor environments (e.g., heat, humidity, ultraviolet/sunlight, among others); the mitigation of indoor aerosol exposure (e.g., air exchanges, filtration, stand-alone air cleaners); the characterization of personal protective equipment effectiveness, disinfection, and re-use; and any potential health effects from increased use of disinfectants. The SAB's advice and additional research recommendations are outlined in the enclosed report.

As the EPA finalizes its research plan, the SAB encourages the Agency to address the panel's concerns raised in the enclosed report and consider their advice and recommendations. The SAB appreciates this opportunity to review EPA's Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19 and looks forward to the EPA's response to these recommendations.

Sincerely,

Dr. Michael Honeycutt, Chair
EPA Science Advisory Board
EPA COVID-19 Review Panel

Enclosure

NOTICE

This report has been written as part of the activities of the EPA Science Advisory Board, a public advisory committee providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use. Reports of the EPA Science Advisory Board are posted on the EPA website at <http://www.epa.gov/sab>.

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ACRONYMS AND ABBREVIATIONS

1		
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4	ACS	American Chemical Society
5	ATSDR	Agency for Toxic Substances and Disease Registry
6	ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
7	AWWA	American Water Works Association
8	CDC	Centers for Disease Control and Prevention
9	CSO	Combined Sewer Overflows
10	CSIRO	Commonwealth Scientific and Industrial Research Organisation
11	DPR	Direct Potable Reuse Treatment
12	HEPA	High-efficiency Particulate Air
13	HID	Human Infectious Dose
14	HVAC	Heating, Ventilation and Air Conditioning
15	IOS	Isopropyl Alcohol/Organofunctional Silane Solution
16	KWR	KWR Institute
17	MERV	Minimum Efficiency Reporting Value
18	NAS	National Academy of Sciences
19	NBACC	National Biodefense Analysis and Countermeasures Center
20	NIEHS	National Institute of Environmental Health Sciences
21	NIH	National Institute of Health
22	NIOSH	National Institute for Occupational Safety and Health
23	NSF	National Sanitation Foundation International
24	OSHA	Occupational Safety and Health Administration
25	ORD	Office of Research and Development
26	PM	Particulate Matter
27	PPE	Personal Protective Equipment
28	RNA	Ribonucleic Acid
29	RV-PCR	Rapid Viability Polymerase Chain Reaction
30	SAB	Science Advisory Board
31	U.S. AMRIID	U.S. Army Medical Research Institute for Infectious Diseases
32	U.S. DOD	U.S. Department of Defense
33	USDA	U.S. Department of Agriculture
34	U.S. EPA	U.S. Environmental Protection Agency
35	USGS	U.S. Geological Service
36	USFWS	U.S. Fish and Wildlife Service
37	UV	Ultraviolet
38	WEF	Water Environment Federation
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1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) review EPA's *Identification of Research Needs to Address the Environmental and Human Health Impacts of COVID-19*. The EPA has a role to help the Nation respond to disasters and emergencies, including threats from biological origins to ensure the protection of human health and the environment. The EPA's Office of Research and Development assessed its research portfolio and has identified research areas where there are opportunities to advance the Agency's capabilities to refine and improve on the current understanding of SARS-CoV-2.

In response to this request, the SAB Staff Office convened a panel of experts drawn from the Chartered Science Advisory Board, the SAB Chemical Assessment Advisory Committee (CAAC), and the SAB Drinking Water Committee (DWC) to provide rapid advice on scientific and technical issues related to the COVID-19 pandemic. The COVID-19 Review Panel, formed under the auspices of the SAB, consists of subject matter experts selected to provide advice on opportunities for current and future EPA research activities that might enhance and inform EPA's current and any future responses to SARS-CoV-2. Dr. Michael Honeycutt was asked to be the Chair of the COVID-19 Review Panel. Sixteen other distinguished scientists accompanied Dr. Honeycutt for this review which began with a teleconference on April 30, 2020.

The SAB anticipates that the scope and scale of the COVID-19 pandemic will lead EPA Program Offices to request additional advice on an array of scientific and technical issues. The SAB believes that rapid advice from nationally recognized scientists and public health experts will assist the Agency in developing and implementing timely and scientifically appropriate responses to the COVID-19 pandemic.

The COVID-19 Review Panel was given a compendium summarizing current understanding and capabilities related to SARS-CoV-2. The document identified short-term and long-term research needs that could build on and extend EPA's understanding of SARS-CoV-2 in different research categories along with a list of four charge questions all of which may be found posted on the SAB website (U.S. EPA SAB, 2020). Written public comments were considered throughout the advisory process.

The remainder of this report is organized by charge questions within each research category. Each section includes a summary followed by the SAB's responses and recommendations. All materials related to the public teleconference and this report are available at:

<https://yosemite.epa.gov/sab/sabproduct.nsf/MeetingCalBOARD/AFBB297A2E1C38258525854C005AD300?OpenDocument>.

2. RESPONSE TO CHARGE QUESTIONS

2.1. Environmental Disinfection

The SAB addressed each charge question. We also provide specific recommendations in the corresponding sections below. The SAB also believes that there are additional research questions important for the EPA to address. These suggested questions are included in the responses to the charge questions.

2.1.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

All short-term and long-term research questions provided by EPA for this research category are clearly described and well-suited to EPA's mission. The EPA is already the lead federal agency on disinfection approaches and has well developed protocols to address these questions. The research questions listed are potentially impactful in responding to the SARS-CoV-2 pandemic.

The research questions in this category are well within the capabilities of the EPA. The public and other partners would benefit from EPA's experience with decontamination issues. The consumer application of the research would benefit from establishing a collaboration with the Consumer Product Safety Commission (<https://www.cpsc.gov/>). Given the urgency of some of the research areas, we recommend that the EPA consider engaging additional research partners (private sector, academia) through its grants and contracts programs.

2.1.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several recommendations with respect to other research questions that should be considered by the EPA. The research questions are listed in Section 2.1.4.

2.1.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other

considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term environmental disinfection research questions and efforts.

- Can basic cleaning techniques (e.g., using soap/water) alone be effective for surfaces to reduce environmental exposure to SARS-CoV-2?

This is an important question, as prior work has found that surgical scrub (containing iodine) were more effective for virus inactivation than just antimicrobial soap. The SAB acknowledges that there are questions on exactly which types of cleaning techniques result in SARS-CoV-2 inactivation and this is an area that requires further research.

- How effective are devices such as ultraviolet (UV), ozone generators or steam devices at reducing or eliminating exposure to SARS-CoV-2 from surfaces or objects?

There are ample studies showing that UV, ozone, and heat (steam) are effective for virus inactivation at well described doses (e.g., temperatures). The SAB believes that this question is a low priority. Given that compatibility with surface materials could be an issue with these technologies, which is a concern for almost all disinfectants, the SAB recommends that the EPA includes this issue into a guidance document.

- What available disinfection methods can be effective for complex and difficult to disinfect areas/surfaces (such as porous materials, soft surfaces, and heating, ventilation and air conditioning (HVAC) units)? What are alternative disinfection methods, if such methods are not readily available or efficacious for an area?

Over 400 products are already available on EPA List N - Disinfectants for Use Against SARS-CoV-2. This list reflects products available to address disinfection on hard surfaces, porous surfaces, and deliver the products as fogs, mists, vapors, or gases. Therefore, a high priority for EPA is to focus on complex and difficult to disinfect areas/surfaces and to develop methods to demonstrate prolonged disinfection. The SAB recommends the use of nano-silver or nano-copper or other modifications for fabric and high-contact surfaces. Similarly, titanium dioxide-coated-photocatalytic surfaces (e.g., glass) have potential to address disinfection. This work could have great impact against SARS-CoV-2 and should be given high priority. The SAB also suggests that the EPA conduct studies on hard (plastic) surfaces and encourages the Agency to include studies that address normal wear and fouling. The accumulation of organic matter and debris in scratches and abrasion on hard surfaces can create environments that can shield viruses from effective contact with the disinfectant.

Thermal disinfection at moderate temperatures has been demonstrated to be highly effective for coronavirus and have potential merit for disinfection of complex areas and surfaces. The development of guidelines and methods to assess disinfection and the impact on surface materials also merits attention.

- What are readily available alternative disinfectants (not currently on EPA List N) for large-scale or special situation use and by what methods can these disinfectants be applied effectively?

The SAB found no products using nano-silver, nano-copper or other modifications on the EPA List N. These products and/or similar products may have particular benefit as long lasting disinfectants. The SAB notes that the effectiveness of surface coatings impregnated with antimicrobials or other antimicrobial surfaces (e.g., silver, copper) could also have high potential in reducing or eliminating exposure to SARS-CoV-2. The SAB regards the evaluation of these products effectiveness, when used alone or in combination, as a high priority area to investigate. Thermal disinfection techniques and guidance development also warrant investigation.

- Do methods of application of List N products via fogging and/or electrostatic spraying provide the necessary contact time on surfaces to be efficacious against SARS-CoV-2?

The EPA has protocols for application methods of disinfectants. The SAB notes that manufacturers may be able to use EPA protocols and/or their own protocols to demonstrate disinfection efficacy. The SAB believes that this question is a low research priority, as the Agency could work with manufacturers to address it.

- How effective are products that claim to offer residual/long-term (e.g., hours to months) ability to reduce potential exposure risk to SARS-CoV-2?

The SAB believes this is a high impact/priority question that the EPA should devote major efforts towards. The ability to demonstrate prolonged virus inactivation would be a significant development for SARS-CoV-2 management. Studies of isopropyl alcohol/organofunctional silane solution (IOS) have shown benefits for bacterial control, but virus inactivation data is sparse. Nano-silver and nano-copper products could also have the capacity to reduce potential exposure risk to SARS-CoV-2.

- What disinfection methods (including using List N products) are suitable for residential and business-owner conducted disinfection?

Many disinfectants and cleaners are targeted towards residential and commercial business applications. As EPA mentioned, the stringency of the registration process provides a high degree of confidence in the effectiveness of these products when used according to the product label (<https://www.epa.gov/pesticide-registration/efficacy-requirements-antimicrobial-pesticides>). Therefore, the SAB regards this question as a low research priority. The SAB recommends that the EPA ensure the labeling and instructions convey adequate and understandable instructions and precautions, including but not limited to, labeling instructions available in multiple languages (see also Section 2.1.4).

- How susceptible to disinfectants are each of the human coronavirus isolates used for antimicrobial product registration, SARS-CoV and SARS-CoV-2? This comparative research may lead to the use of a safer-to-handle surrogate virus for future regulatory and research purposes, thus facilitating additional product and technology development.

Examining various strains of SARS-CoV and SARS-CoV-2 and other coronaviruses could yield interesting variations in resistance with major differences. However, differences impacting the selection of a disinfectant dose are less likely. To date, studies of disinfectants on MERS, SARS-CoV, and SARS-CoV-2 have found high efficacy without any evidence of resistant strains. While this line of research is interesting in that it will help with the basic understanding of disinfection for these viruses, it is more likely a long-term study than a short-term need.

Long-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's long-term environmental disinfection research questions and efforts.

- Are there situations where environmental disinfection of surfaces or objects may not be effective to reduce or eliminate potential exposure to SARS-CoV-2?

Disinfection efficacy can be influenced by the presence of organic matter, dirt, biofilm, and other debris that can block the action of the disinfectant. In these cases, cleaning of the surface, followed by disinfection, would be most appropriate. The SAB recommends that the EPA investigate conditions that prompt the use of several procedures to result in SARS-CoV-2 inactivation.

- In situations where the frequency of recontamination is high, how often is disinfection needed to effectively reduce or eliminate potential exposure to SARS-CoV-2?

This question is highly based on the frequency of recontamination, rather than the efficacy of disinfection. This question is more appropriate for long-term disinfectants and factors that impair the long-term efficacy.

- If SARS-CoV-2 is airborne and continues to settle onto surfaces (e.g., after surface disinfection), does disinfection of surfaces alone effectively reduce potential exposure to SARS-CoV-2?

This question is focused on understanding the route of infection (i.e., aerosols versus exposure contact), rather than how to disinfect the virus. The SAB recommends removing this question from this list and consider it under the Environmental Exposure research category. It is more relevant when multiple avenues of disinfection (e.g., air, surfaces, hands, etc.) are considered to minimize risk.

- How effective are surface coatings impregnated with antimicrobials or other antimicrobial surfaces (e.g. copper) in reducing or eliminating exposure to SARS-CoV-2 and how should disinfectants be used in combination with these treated surfaces?

This is an important question. The SAB recommends this question to be addressed as a short-term research objective (see specific recommendations outlined above). Examination of nano-silver, nano-copper, or other modifications is highly recommended. Isopropyl alcohol/organofunctional silane solution (IOS) have shown benefits for bacterial control, but virus inactivation data is sparse. The use of combinations of disinfectants and cleaning procedures is also recommended.

2.1.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The research questions posed by EPA largely focus on specific disinfectants, surfaces, or delivery methods. The SAB recommends that the EPA consider a more holistic approach to SARS-CoV-2 disinfection based on a systems level. The SAB has a few questions about parameters and input data that could be strengthened going forward.

- What guidance can EPA provide for disinfection at a building level, for vehicles, or public transportation (e.g., cars, subways, trains, busses, airplanes, etc.)?
- Could UV disinfection within HVAC systems (along with high-efficiency particulate air (HEPA) or electrostatic filters, in vacant rooms or at night) be effective systems control?
- Could overnight, moderate-temperature thermal disinfection of surfaces or vacant rooms provide effective disinfection for businesses and public rooms?

The safety of disinfection methods and products, particularly when used in combinations or when deployed as fogs, mists, vapors, or gases needs to be carefully monitored and controlled. The re-volatilization of some of the disinfectants could be a concern after application. The SAB notes that the human health risks to the public during and after a disinfectant application should be further evaluated. The formation of disinfectant by-products could pose a potential hazard to the public and both for dermal and inhalation exposures should be considered. The SAB suggests that in situations where disinfectants are applied in childcare settings, or where oral exposure to disinfectant residuals is highly possible, these types of settings offer a research category that should be considered further as a high priority for the Agency.

2.2. Environmental Sample Collection Methods

The SAB acknowledges that the research questions in this category assume that the transmission of SARS-CoV-2 is predominantly from emitted droplets from infected persons to surfaces for pickup for transfer to the upper respiratory tract of others, rather than infection via inhalation of expelled aerosol from infected subjects. The SAB provides a detailed discussion about why direct infection via inhalation of expelled aerosol from infected subjects is most likely to be the predominant mechanism of disease transmission for this virus (see Section 2.5). Acknowledging that the inhalation of expelled aerosol is a significant route of exposure and infection opens a new series of methodical questions for environmental sample collection. Environmental sample collection of respirable aerosols should fit directly into this category.

The SAB believes that there are additional research questions important for the EPA to address. These suggested research questions are included in the responses below to the specific charge questions. We also provide specific recommendations in corresponding sections below.

2.2.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

The SAB finds that all research questions for this research category are clearly described and are well-suited to EPA's mission. The SAB notes that this research category is inextricably linked to the various research categories, including *Environmental Sample Analysis* (Section 2.3) and *Environmental Exposures* (Section 2.5), and encourages the EPA to regard the comments provided in this research category when considering those comments. The ability to accurately collect and process samples is critical to assess both risk assessment and mitigation efforts to manage the SARS-CoV-2 pandemic. The research questions related to environmental collection and monitoring are central to EPA's current activities. The SAB believes that the Agency has deep expertise in these areas.

The SAB notes that the U.S. Geological Service (USGS) also has deep expertise in some of these areas and could be consulted to establish collaborations. Recently, the National Academy of Science (NAS) provided expert consultation on a variety of topics related to COVID-19 (NAS, 2020). The SAB suggests that the EPA conduct a comprehensive literature review to identify other scientists working on these key research issues. Additional comments aimed at improving the clarity of specific research questions are given below.

2.2.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

Environmental Sample Collection of Respirable Aerosols

As mentioned above, acknowledging that the inhalation of expelled aerosol is a significant route of exposure and infection opens a new series of methodical questions related to environmental sample collection. The collection of respirable aerosols should fit directly into this category. For example, the National Institute for Occupational Safety and Health (NIOSH) has developed a methodology to detect infectious airborne influenza virus using the NIOSH bioaerosol sampler (Cao, 2011). Other samplers that collect bioaerosols may be reasonable choices (e.g., SKC BioSampler). Furthermore, a recent article presents a photographic/imaging technique from Japan that allows for a direct spatial visualization of person-emitted aerosol in the critical size range of 0.1 to 100 microns aerodynamic diameter (Broom, 2020). This technique could be used to evaluate the risk of exposure to potentially virus laden aerosol droplets in various indoor and outdoor environments.

Statistical sampling strategies (e.g., numbers, locations, frequency) are typically driven by the distance between the exposure that is measured or measurable versus a benchmark for “allowable” exposure. If there is a large separation or distance between these two values, then there is no need for a highly precise measurement of exposure. The number of samples required is also relatively small and the natural variation or error in the method can be relatively large. Non-detects values can be used (i.e., values below the limits of detection) if the limits of detection are low enough, relatively to the benchmark for allowable exposure. A well-defined exposure limit or a reasonably defined distribution of effects over a range of exposures could render a reasonable exposure assessment (Jahn, 2015). A data point selected from that distribution can then be used to set a deterministic exposure limit (e.g., the 5th percentile). The SAB notes that if the available sampling equipment/resources are not showing a prescribed level of conformance relevant to the selected exposure limit, then this is an area that needs to be researched.

Short-Term Research Questions

The SAB has several recommendations and provides areas for consideration with respect to EPA’s short-term environmental sample collection methods research questions and efforts.

- Under what situations does environmental contamination need to be assessed (e.g., when is it useful to enhance or enable decision-making)?

The need for environmental contamination assessments will be driven by the circumstances. Currently, there is a clear need to monitor high traffic areas (e.g., subways, buses, airplanes, office buildings, etc.) with the purpose of reducing exposure.

- What methods (e.g., swabs, wipes, material types) are most appropriate for surface sample collection of SARS-CoV-2?

A variety of sampling techniques will be needed, including swabs, wipes, grab and composite sampling. The methods used for surface sample collection of SARS-CoV-2 should provide sufficient sensitivity for risk assessments. The most appropriate methods will detect the smallest number of viral particles. If the infectious dose is 200 viral particles, a method that detects 100 viral particles may be unnecessary and more expensive without additional benefit. Ultimately, the SAB notes that a high priority task should be the identification of an infectious dose and understanding how this dose may be different according to different populations of individuals.

- What are the detection limits and sample collection efficiencies specifically for SARS-CoV-2 for various environmental sample collection methods?

This is a key, high priority, research question that precedes the previous questions in terms of priority. The SAB believes that the EPA can provide input on sampling techniques, analytical methods and their sensitivity. Evaluating sample collection methodology and protocols should be part of any environmental sampling program. The EPA is in a strong position to establish protocols that could be used by different agencies throughout the country. Conducting the sampling using standardized methods will allow the data from each agency to be pooled confidently for the development of public policy. Lastly, the EPA should replace “environmental sample collection methods” with “surface sample collection methods” in this research question to be more consistent with the previous question. As mentioned above, other media such as “air” is not included here and should to be addressed.

- What environmental sampling strategy(ies) (including number of samples, sample locations, frequency of sampling, and timing of sampling) will provide the most effective characterization of the presence/absence of SAR-CoV-2 on both non-porous and porous surfaces?

The SAB notes that the environmental monitoring guideline entitled: “Biological Field and Laboratory Methods” (EPA-670/4-73-001) developed by EPA in 1973 could be updated as part of this effort to address the environmental sampling questions raised here and the number of samples needed to ensure a high degree of confidence in the results.

Monitoring programs conducted by the USGS related to storm events can be used as models to address issues such as sample locations, frequency and timing of sampling. As pandemic events are considered “episodic” like storm events, routine environmental sampling approaches (i.e., annual, semi-annual, or quarterly sampling) are not likely to provide the same degree of information. The work conducted on storm sampling by the USGS illustrates that environmental sampling needs to be based on the duration of the event to capture episodic situations. This research area encompasses many traditional questions related to environmental monitoring. The SAB notes that there should be a robust basis for making these sampling determinations as they are highly dependent on other research questions being answered first. The SAB believes that EPA’s guidance and expertise would prove valuable in this research category to ensure that proper sampling designs are considered.

2.2.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other

considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

As mentioned above, setting criteria for adequate detection limits and sampling design (e.g., number of samples, replicates, frequency) are among the highest priorities in this research category. While all the suggested research questions in this category are valuable, questions that are more attainable and can be completed quickly could have a great impact on the characterization of the presence/absence of SARS-CoV-2. The SAB also suggests that the EPA consider a variety of training approaches (e.g., virtual workshops, videos, pamphlets, etc.) to establish a national program for SARS-CoV-2 sampling and mitigation measures.

2.2.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

All the research categories overlap with one another. The SAB recommends that the EPA organize the research categories using basic risk assessment elements. Sections 2.7 and 2.8. provide additional recommendations that could help the EPA organize the research questions to reflect what is known about the cause-effect pathways and what is not known about SARS-CoV-2.

List of Risk Assessment Elements

- Risk = f (Exposure)(Hazard/Exposure)
- Hazard/Exposure = Potency
- Hazard identification — characterization of innate adverse toxic effects of agents.
- Dose-response assessment — characterization of the relation between doses and incidences of adverse effects in exposed populations.
- Dose-Response Metrics (e.g. response to the number of virus delivered to the pulmonary region versus number dosed to upper respiratory tract).
- Exposure assessment — measurement or estimation of the intensity, frequency, and duration of human exposures to agents.
- Exposure Metrics (e.g. number of virus in pulmonary region versus number dosed to upper respiratory tract).
- Risk characterization — estimation of the incidence of health effects under the various conditions of human exposure.

2.3. Environmental Sample Analysis

The SAB believes that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.3.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

All research questions provided by EPA are appropriate and well-suited to EPA's mission, and will be central to EPA's role in responding to the COVID-19 pandemic. Having accurate, sensitive, and specific analytical methods will be important for making correct determinations regarding risk and mitigation. The SAB believes that establishing standard methods and detection limits for these methods is critical to ensuring any data collected by a prescribed method can be relied upon by scientists who inform policy makers regarding the efficacy of safeguards in place or additional measures that need to be taken. Developing analytical methods that can detect virus particles to below infectious dose levels is critical to ensuring that measures taken are sufficient and robust enough to protect the human population. The SAB notes that this research category is inextricably linked to the *Environmental Sample Collection Methods* (Section 2.2) research category and encourages that the EPA regard the comments provided in this research category when considering those comments.

Furthermore, analytical methods for determination of SARS-CoV-2 are being pursued by several universities, research agencies and commercial laboratories (e.g., the Water Research Foundation, the KWR Institute in the Netherlands, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, among others). It will be important for EPA to serve as a liaison between these agencies or organizations to coordinate this effort and avoid duplication. As a federal agency, EPA is in a unique position to establish critical parameters related to detection limits for virus assays. The Agency should work with associations like the American Society for Microbiologists to formulate and establish protocols that can be followed so these critical parameters can be determined whenever the need arises.

The SAB recommends that the EPA work with other organizations such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Water Works Association (AWWA), the Water Environment Federation (WEF), the National Sanitation Foundation (NSF) International, and the American Chemical Society (ACS) to ensure that EPA's research can also be used to inform the needs of these organizations. Many of these organizations provide guidance to their constituents in public health protection areas that are not directly under EPA's purview. In the

absence of EPA's regulatory authority, these partners play an important role in protecting public health and providing guidance to their constituents in implementing best management practices. With that said, the SAB suggests that the EPA conduct the scientific research to inform and provide guidance.

2.3.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The rapid viability polymerase chain reaction (RV-PCR) work being conducted by the EPA is critical and should be completed as expeditiously as possible. It will also need to be examined and validated by other laboratories. This has been a major research need, and if the method is independently validated, it would be a significant contribution to science. If successful, this research could aid other EPA programs by reducing sample completion times and reducing the cost of virus analysis (e.g., improving sample collection efficiency as it is still a barrier to improving detection capability). The SAB believes that a less expensive and more rapid response time would improve EPA's understanding of the fate of the virus in the environment.

2.3.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB has several recommendations and provides areas for consideration with respect to long-term environmental disinfection research questions and efforts. Comments regarding prioritization are embedded in the discussion below.

- What are the SARS-CoV-2 sample analysis objectives (adequate specificity, limits of detection, viability assessment, turnaround time) and which methods are most suitable or can be developed to meet those objectives?

The accuracy and precision of the data derived from environmental sampling could be used to predict the human exposure risks and establish public policy. The SAB notes that it is critical to establish the specificity, accuracy, and precision of the SARS-CoV-2 assays to ensure that public policy can be based on the proper interpretation of data. As analytical capabilities continue to improve, this will be an ongoing task for the EPA. The SAB believes that this research question is both a short-term and long-term task for the Agency.

Furthermore, it is critical to develop performance objectives for the analytical methods, particularly as they can inform risk management actions. For example, the fact that PCR methods do not measure infectivity is not critical if the objective of analysis is to show the elimination of viral ribonucleic acid (RNA) by cleaning or disinfection procedures. However, for risk determinations, an assessment of infectivity could be important. Given that many disinfection techniques can create nucleic lesions preventing the application of inactivated virions, the SAB notes that the use of long read primers

(McLellan, 2016), long range amplicons (Wolf, 2009) and viability dyes (Randazzo, 2016) have shown some promise for molecular analyses.

- What are the most appropriate sample custody, preservation, transport, and storage conditions to maintain sample viability prior to analysis for SARS-CoV-2?

The SAB regards this research question as a low research priority. The SAB notes that this is an important question, but one that mostly pertains to enveloped viruses (i.e., a virus that has an outer wrapping or envelope).

- What is the current laboratory capability and capacity for molecular and viability analysis for SARS-CoV-2 and what method improvements can be made to increase capability/capacity? How does this reflect on the required environmental sample analysis needs?

The SAB recommends that the EPA initiate or assist in a national monitoring program for water/wastewater, air, building decontamination, as well as support the critical aspects of availability, capacity, training, and coordination of molecular and viability analysis for SARS-CoV-2. Proficiency tests, controls, and inter-laboratory comparisons will need to be performed to obtain accurate analyses. Currently, there is a research gap in the ability of environmental laboratories to perform these analyses. The SAB thinks that the EPA should identify this issue as a key research need. The SAB also recommends that the EPA coordinate with other federal and non-federal laboratories to assist with scaling up testing and enhance laboratory capacity.

2.3.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

2.4. Environmental Stability/Persistence on Surfaces

The SAB believes that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.4.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

Overall, the SAB finds that the research questions for this category are clearly described and are well-suited to EPA's mission. The research questions in this research category are well within the capabilities of the EPA and would benefit from their experience with such issues. Nonetheless, the SAB notes that the EPA should consider whether there are other government or academic laboratories addressing similar research questions, and whether collaborations or partnerships with other research institutions could enable synergies or advance research beyond what would occur with parallel independent efforts. For example, both the National Biodefense Analysis and Countermeasures Center (NBACC) and Rocky Mountain Laboratories are studying effects of temperature and humidity on SARS-CoV-2 survival. The NBACC is also planning to test effects of solar radiation on SARS-CoV-2 survival.

2.4.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB acknowledges that some of the recommendations listed below are inextricably linked to other research categories and encourages that the EPA regard the comments provided in this research category when considering comments in the *Environmental Exposure* (Section 2.5) and *Air* (Section 2.7) research categories. Given the importance or even dominance of virus in aerosol expelled by individuals infected with SARS-CoV-2, supplementary questions could be generated around the stability of the virus in aerosol or other fomites in air.

The SAB has several recommendations and provides areas for consideration with respect to EPA's environmental stability research questions and efforts.

- How long does SARS-CoV-2 remain viable on nano-coated surfaces? If such surfaces reduce viability, temporary or removable nano-enabled coatings, could they be applied to frequently

contacted surfaces (e.g., railings or door handles)? Could they augment, or potentially reduce the use of disinfectants?

- How do heat, humidity and UV or sunlight interact with respect to viral persistence and infectivity, both indoors and outdoors? See Section 2.7 for additional recommendations.
- Are the effects of heat and humidity on SARS-CoV-2 viability similar across types of surfaces, or are there heat/humidity-surface interactions, with surface-dependent effects (e.g., hard vs. porous surfaces)? See Section 2.1 for additional recommendations.
- How long does SARS-CoV-2 remain viable on groceries, and consequently, what is the probability that there are viable levels of SARS-CoV-2 on groceries when they arrive at the home?
- How long does SARS-CoV-2 remain viable on PPE, such as masks, gloves? See Section 2.9 for additional recommendations.
- How long does SARS-CoV-2 remain viable on surfaces typically found at children's microenvironments, such as playgrounds (e.g., slides, swings, climbing equipment), and does viability of SARS-CoV-2 on such surfaces depend on ambient conditions such as sunlight or cloud cover. This question could inform whether children's microenvironments could be safely used (while maintaining appropriate social distance). See Sections 2.7 and 2.8 for additional recommendations.
- In addition to glass and stainless steel, how long does SARS-CoV-2 remain viable on hard plastic surfaces that have some degree of surface damage, which may house a waxy grime that could extend the viable life of the virus?

2.4.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

While all the suggested research questions in this category are valuable, the SAB finds the following areas to have the greatest impact and suggests given them higher priority:

- How long does SARS-CoV-2 remain viable on surfaces in outdoor conditions such as direct sunlight and various levels of relative humidity, temperature and precipitation?
- How long can SARS-CoV-2 remain viable on fomites (e.g., dust)?
- How long can SARS-CoV-2 remain viable on mail or clothing, and does it pose a take-home risk?

The SAB notes that it is not clear how the question "How does temperature and humidity impact persistence indoors" differs from the question "Can alternate environmental conditions (heat and

humidity) be used to effectively reduce or eliminate the presence of SARS-CoV-2 on environmental surfaces?” Nonetheless, once effects of heat, humidity and UV/sunlight are known, consideration can be given to define conditions that would promote virus inactivation (e.g., Could installation of UV lights in HVAC systems and areas of air exchange facilitate virus inactivation?). See Sections 2.1 and 2.7 for additional recommendations.

With respect to how long SARS-CoV-2 remains active on frequently touched surfaces, there are two potential measures: 1) the amount of viral nucleic acids; and 2) the viral infectivity or titer. Whereas the first measure is relatively straightforward and could be more readily addressed in the short-term, viral infectivity is more relevant, and hence, considered the gold standard.

2.4.4. Charge Question 4

Are there any other important categories of research, focused on the Agency’s role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA’s efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency’s capabilities and improve on the current understanding of SARS-CoV-2.

2.5. Environmental Exposure

Overall, the SAB finds that the EPA document is a good start in defining the environmental exposure research needs to assess SARS-CoV-2. The SAB strongly believes that this research category should be enhanced with the consideration of the inhalation exposure route as a critical element of the environmental exposure research to be conducted by the Agency. There is evidence about the importance of inhalation of expelled aerosol from infected individuals as a predominant factor in the risk assessment of SARS-CoV-2. The SAB presented some of this evidence as part of the public teleconference on April 30, 2020 (Jayjock, 2020). All the meeting materials are available on the SAB website. The information presented during the public teleconference has been expanded in this section as discussed below.

The classic expression of human health risk from external agents is that it is a function of both exposure to and potency of that agent. The equations below present this concept:

- Risk = f (Exposure)(Hazard/Exposure)
- Hazard/Exposure = Potency

The SAB finds that in order to appropriately assess the exposure transmission of COVID-19, the critical metrics of both hazard and potency needs to be comprehended to devise the proper metrics of exposure and risk. If the hazard to humans from SARS-COV-2 comes predominantly from droplets => surfaces => hands => upper respiratory tract, then these relationships dictates the scope and methods of research. However, the SAB notes that if inhalation of aerosol expelled from infected people is the significant or dominant source of exposure and risk, then the critical parameters of this mechanism need to be a research priority.

There is significant scientific evidence for the importance (perhaps predominance) of inhalation of SARS-CoV-2 from expelled aerosol from infected individuals causing the transmission of human-to-human of COVID-19. In a review article on influenza virus, Tellier (2006) reports a 40- to 500-fold difference in human infectious dose (HID) between study data with aerosol inoculated subjects (Alford, 1966) when compared to a different study in which the inoculation done was via intranasal drops (Douglas, 1975). That is, the dose was an order of magnitude or two more infectious per administered viral unit when given by inhalation of respirable particles. Also, the influenza disease observed in human study participants infected experimentally by intranasal drops was reportedly milder, with a longer incubation time and usually no involvement of the lower respiratory tract (Little, 1979).

For safety reasons, these findings reportedly led to the adoption of intranasal drop inoculation as the standard procedure in human experimental infections with influenza virus drops (Douglas, 1975). Given the above evidence that at least influenza virus is highly infectious via inhalation of expelled aerosol from infected humans, how likely is human exposure to expelled aerosol containing SAR-CoV-2 virus? If an airborne particle of mostly water is smaller than 10 microns, it can penetrate and deposit in the pulmonary (alveolar) region of the lung. When we cough, sneeze, speak or simply exhale, we emit a continuum of particle sizes ranging from less than 1 micron to over 1,400 microns (Nicas, 2005; Chao, 2009; Lindsley, 2010; Milton, 2013; Bourouiba, 2014; Skaria, 2014; MacIntyre, 2016). A study published in 2009 found that half the particles emitted by healthy subjects were less than 8 microns

1 aerodynamic diameter (Chao, 2009). It also found that many more particles were emitted in a cough
2 compared to speaking.
3

4 Furthermore, in a study conducted by Milton et al., particles emitted by subjects with influenza were
5 collected in two size fractions – less than 5 microns and greater than 5 microns. The viral RNA content
6 was quantified by a standard PCR method (Milton, 2013). Based on the particle size data for human-
7 emitted aerosol, only a tiny percentage of the total fluid volume in emitted particles is expected to be
8 contained in those smaller than 5 microns, yet 90% of the virus particles were found in these small
9 (respirable) particles. The SAB notes that these particles can deposit into the deepest part of the lung, the
10 alveoli. In a similar study, particles from subjects with influenza were collected in three fractions: less
11 than 1 micron, 1 to 4 microns, and greater than 4 microns (Lindsley, 2010). The majority (65%) of virus
12 particles were found in the fraction less than 4 microns.
13

14 In answering the question about how likely expelled aerosol is to cause human exposure to SARS-CoV-
15 2, the SAB finds that it will be useful to consider how long these relatively small, virus-laden particles
16 remain in the air. For example, if a 5-micron particle were emitted into still air at 5 feet above floor
17 level, it would take about 33 minutes to settle. During that settling time, a 5-micron particle can travel a
18 considerable distance in typical indoor air environments in occupational, institutional, or residential
19 environments. During this settling period, these particles could travel more than 6 feet; however, their
20 concentration per unit volume of air will be significantly decreased. A recent study (Bourouiba, 2014)
21 presented a fluid mechanics and visual analysis of the path and distance traveled by particles in a cough.
22 According to the authors, particles less than 10 microns in diameter “would remain suspended in a
23 cough cloud meters away from the cougher.” The SAB recommends that the EPA evaluate the following
24 research question: what is the distance an infectious dose of SARS-CoV-2 aerosol can travel from an
25 expelling source or source(s) indoors?
26

27 Moreover, the EPA’s document states that: “Researchers believe that the infectious dose for SARS-
28 CoV-2 is less than that for SARS (estimated for SARS as an average of 240 viral particles).” The
29 document cited two references: De Albuquerque et al., 2006 and the reference Dediego et al., 2008. The
30 SAB was unable to find the value of 240 viral particles in either of these references. However, both
31 studies state that the animals were dosed via nasal deposition. Questions remain about the value of viral
32 particles for nasal dosing (e.g., was the value of nasal dosing divided by a factor to extrapolate between
33 animals and humans). See information mentioned above about experimental evidence on the relative
34 potency of inhaled versus nasal instilled virus.
35

36 Based on these facts, the SAB strongly believes that expelled infected aerosol exposure is critical in the
37 risk assessment of COVID-19 and should be included in any planned research program. The SAB notes
38 that there are good animal models available for studying the infectious dose via both nasal installation
39 and aerosol challenge. These models should also be used to assess the risk of human exposure to SARS-
40 COV-2 from both deposited droplets and aerosol, if appropriate.
41

42 The SAB believes that there are additional research questions important for EPA to address. These
43 questions are included in the responses to the charge questions. We also provide specific
44 recommendations in corresponding sections below.
45
46
47
48

2.5.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

The SAB finds that all research questions are within the EPA's mission and the research work cannot be more effectively addressed by other Federal partners, state agencies, the private sector, or academia. We believe that the questions presented above about aerosol exposure could lead to the development and implementation of mitigation measures that will have the most impact to society. The SAB believes that such work will protect public health and help government with reopening society.

The SAB also finds that collaboration with other groups is necessary and, if funds were made available, these research efforts could potentially be more productive by bringing in additional expertise and helping with capacity. Potential partnering agencies include but are not limited to: Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Fish and Wildlife Service (USFWS), National Institute of Environmental Health Sciences (NIEHS), National Institute of Health (NIH) and U.S. Department of Agriculture (USDA) as well as state health and environmental departments. The private sector and academia could also be effective partners.

2.5.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several recommendations and provides areas for consideration with respect to EPA's environmental exposure research questions. It is vital to identify the key potential sources and pathways of exposure as well as the routes of exposure, as together they will inform where preventive measures and/or mitigation are needed. The SAB acknowledges that some of the recommendations listed below are inextricably linked to other research categories and encourages that the EPA regard the comments provided in this research category when considering those comments.

Exposure Sampling

The SAB recommends that EPA conduct a study to measure viable SARS-CoV-2 levels in air in buildings and other microenvironments, to help characterize exposure in specific type of buildings, and which conditions likely lead to higher levels of exposure (see Section 2.7 for more recommendations). For example, office buildings will be important, as opening those settings will be imperative for opening the economy. The SAB notes that monitoring should occur in multiple locations within the building to

determine if once individuals get through the common areas, their exposure is reduced (e.g., the lobby; elevators due to individuals passing through; bathrooms; individual floors; food service areas; among others). The SAB notes that the levels of CO₂ could simultaneously be measured to determine the relative number of people versus air exchange rates. Small and medium commercial buildings could also be monitored, as building size may be an important predictor for potential exposure (see Section 2.7 for more recommendations about research conditions).

Furthermore, the SAB recommends that fixed areas that are part of public transit be evaluated (e.g., stations, number of cars, and buses, among others). For example, individuals going through each station, riding on a given car or bus could be potential predictors of exposure. The SAB notes that careful consideration should be given to other potential factors that could influence individual exposures to ultimately provide guidance on what types of scenarios and possible mitigation strategies would be helpful. Additional research activities should be completed to develop or refine personal monitors and/or monitoring equipment viable for SARS-CoV-2. Exposure assessments can be completed on an individual basis to help identify behaviors related, but not limited to, work activities (e.g., mail carrier, delivery personnel, cab drivers, medical personnel). The SAB notes that personal monitors could also be useful in evaluating the effectiveness of personal protective equipment and in the development of exposure assessments (see Sections 2.8 and 2.9 for additional recommendations).

Exposure Mitigation

Several studies have shown that there are insufficient levels of air exchange in classrooms to even maintain levels of CO₂ required by standards. Heating, Ventilation and Air Conditioning (HVAC) systems are often not set to bring in adequate levels of outdoor air. The EPA should consider whether classrooms should keep windows open, and if possible, have HVAC systems set to maximize delivery of outdoor air in order to minimize the lifetime of particles in classrooms. Similar considerations should be made for office buildings and cubicles of all sizes. The SAB acknowledges that there may be additional considerations when increasing air exchange rates, including potential increase in energy costs associated with operating buildings. Yet, this is a research question worth exploring, if risks could be reduced.

As referenced in National Academy of Sciences Rapid Expert Consultations on the COVID-19 (2020), several studies have shown that survival of the virus is reduced by higher temperatures and humidity. The SAB recommends that these parameters be evaluated from the perspective of identifying optimal operating parameters for building HVAC systems (see Section 2.7 for additional recommendations). Both high efficiency stand-alone air cleaners and high efficiency filters in HVAC systems have been found to reduce particle loading in homes. While commercial buildings theoretically require higher Minimum Efficiency Reporting Value (MERV) performance filters than homes, these regulations are not always followed, and stand-alone air cleaners may be effective in reducing virus loads in confined areas where there are people passing through. Although these mitigation methods may be limited by the supply chain (available units), the SAB recommends the evaluation of whether increasing the MERV filters value and increasing both the intake of outdoor air and the rate of air passing through filters decreases virus concentrations (see Section 2.7 for additional recommendations).

The SAB notes that there has been considerable messaging in terms of public education regarding hand washing and face touching. These activities will be important when individuals transition between settings (e.g., from home to school, to the workplace or public areas). It will be important that individuals abide by these recommendations to reduce exposures. The SAB recommends that the EPA

work with public health partners to determine if there are opportunities to increase the effectiveness of this messaging.

The SAB recognizes that there are a variety of masks, face shields, and stationary shields being used to protect the general public and workers (see Section 2.9 for additional recommendations). The use and care of personal protective equipment (PPE) is important for their effectiveness. Previous work has demonstrated the strengths and weaknesses of the different types and combinations of PPE. The report from National Academy of Sciences (NAS) Rapid Expert Consultation on the Effectiveness of Fabric Masks for the COVID-19 Pandemic (April 8, 2020) states that the available information on the effectiveness of homemade cloth masks is inconclusive. The NAS report provides information about the limited research available related to how the behavior of the individuals wearing masks plays a role in their effectiveness. The SAB believes that this is an area of research that could be accomplished and include the use of face shields (as a stand-alone PPE) and/or in combination with masks.

2.5.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB recommends that the EPA focus on measures to prevent and mitigate environmental exposures. Although research should be conducted on all potential exposures, EPA's research priorities should be focused on the pathways with the greatest potential exposure. The SAB recognizes that multiple research questions would need to be answered to accomplish this endeavor and advises that the EPA focus on research questions that could inform mitigation strategies. Additionally, the SAB recommends that the EPA investigate and evaluate mitigative measures that are feasible and easily implemented by the general public (e.g., measures and/or activities using household appliances or the use of sunlight to disinfect items).

2.5.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate: 1) the potential for wildlife and/or domestic animals to be carriers (reservoir) of the SARS-CoV-2 virus, and 2) the interaction between wildlife and/or domestic animals with humans as a potential source of exposure. The SARS-CoV-2 virus is thought to have a zoonotic origin and come from bats (Yuan, 2020). The World Organization for Animal Health (2020) provides a summary of reports of various species of animals that have tested positive and they recommend that humans who test positive minimize their interaction with pets and farm animals. Additional evaluation on whether interspecies transfer of viable virus and the potential existence of animal reservoirs is needed. The SAB notes that the completion of a literature review could inform a final decision about whether this is a short-term or long-term research effort.

1 Lastly, the SAB notes that the research recommendations provided in this document are important in the
2 evaluation of the highest potential exposures associated with reopening our society. Even when an
3 effective vaccine is developed for COVID-19, the research questions and categories identified by EPA,
4 including the depth of information capture here, will be useful for future pandemics.

2.6. Water/Wastewater

Overall, the SAB finds that the research questions posed by EPA in this research category are well-considered, relevant, and clear. The research questions address EPA's mission of protecting public health and the environment. The SAB recommends that the EPA take this opportunity to clarify the nexus between the stated research questions and the Agency's regulatory activities. The SAB recommends that the EPA determine whether compliance with existing regulations provides protection against COVID-19 (i.e., whether exposure to pollutants within or below current regulatory limits leads to higher transmission rates, exacerbates morbidity or mortality, or increases susceptibility in the context of SARS-CoV-2). These findings could provide reassurance to the public that compliance with existing environmental regulations is sufficient, beneficial and important.

The SAB believes that there are additional research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.6.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. *Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*

The SAB notes that the bullets included in the "Current State of Knowledge" column for "Water/Wastewater," reflect current understanding regarding the threat posed by the virus. As stated in EPA's document, the bullets identified several research opportunities. The bullets are:

- Based on existing CDC information there is no indication that water or wastewater exposures pose a significant risk to human health.
- There is limited research to suggest that the virus might be transmitted via the fecal-oral route.

While the SAB believes that the issue of direct fecal-oral transmission is outside of the scope of this research category, there are important questions that remain regarding waterborne transmission of the SARS-CoV-2 virus. Research assessing the efficacy of treatment unit processes on removing or inactivating the SARS-CoV-2 virus is needed to assure the general public that the current drinking water and wastewater treatment frameworks provide adequately protect public health.

In environmental settings where waterborne transmission is possible (e.g., swimming pools, hot tubs, beaches, combined sewer overflows, etc.), the SAB agrees that research should be conducted to ensure the risk of waterborne transmission is minimized. However, the EPA should recognize that the public may not be protected from direct fecal discharges in these settings. Some specific areas of research include, but should not be limited to:

- The need for information on the SARS-CoV-2 viral load in urine of infected individuals (as especially young children often urinate directly in pools).
- The kinetics of SARS- CoV-2 inactivation in various water matrices (e.g., saltwater pools - often with lower disinfectant dosing; freshwater pools; lake water; among others).
- The disinfection efficacy and kinetics of a suite of secondary disinfectants.
- The direct monitoring of SARS-CoV-2 levels in pools, hot tubs, and recreational waters.

The SAB agrees that disinfection chemistry is complex. When chlorine is used as a disinfectant in freshwater pools, chlorine can react with ammonia and amines (often from urine in the pool) to form a host of secondary oxidants. Specifically, breakpoint chlorination chemistry describes the formation of monochloramine, dichloramine, trichloramine, nitrogen gas with little oxidant residual, and free chlorine after the breakpoint. Furthermore, in saltwater, bromide above 1 mg/L in the water allows conversion of free chlorine to free bromine (and chloramines to bromamines) leading to bromamine formation. The SAB notes that the disinfection efficacy for SARS-CoV-2 will likely vary in swimming pools and hot tubs depending on chlorine or other disinfectant dosing approach and the water quality parameters (e.g., pH, total dissolved solids, etc). The SAB recommends that the EPA partner with public health officials as there is a need for the public to understand the level of risk associated with these water bodies.

The SAB believes that the EPA is well-suited to summarize and evaluate the effectiveness of disinfectants on SARS-CoV-2 virus. However, the SAB notes that the citation (27) used as a reference regarding disinfectants, covers best practices for environmental cleaning in a healthcare facility and does not reflect the extensive background the Agency has on the disinfection of water and/or wastewater. The SAB recommends that the EPA use the following references: 1) the Surface Water Treatment Rule; 2) the Total Coliform Rule; 3) the National Pollutant Discharge Elimination System (NPDES) disinfection; and 4) the Recreational Waters guidance materials. These references would better reflect the breadth of knowledge and experience the Agency has with disinfection, as it applies to the production of drinking water and treatment of wastewater. The SAB believes that this knowledge is not reflected adequately in the “Current State of Knowledge” column under the “Water/Wastewater” heading.

b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?

The EPA presentation identified monitoring of wastewater as an important area of research to assess the rate of infection within a community. While the SAB believes this is a laudable objective, it is not clear how the EPA’s proposed approach improves the current disease reporting system used by the CDC. By making COVID-19 a reportable disease in the CDC reporting system, the health testing results would be used to establish infection rates in a community. Given the current state of knowledge, the SAB believes that it would be more advantageous to use CDC’s existing system, rather than establishing a community infection rate using environmental samples. The monitoring of wastewater would need to be adjusted based on: 1) travel time in the sewer, which is highly variable depending on location of discharge to the sewer; 2) attenuation of the virus during travel to the point of sampling, shedding rate (which may be variable due to stage of disease in person); and 3) limitations of the analytical method (e.g., limit of detection). Each of these variables could create and/or add uncertainty to an infection rate calculated from a raw wastewater sample.

The SAB notes that other programs, such as monitoring over the counter medications sales, could be useful in monitoring the health of a community because new monitoring approaches can be developed using artificial intelligence and existing systems. Such systems could also be formatted to send warnings when the sales of a certain types of over-the-counter medications exceed baseline levels.

However, the SAB recognizes that in communities, particularly smaller communities, where limited or no personal testing is available, wastewater testing could potentially be useful as part of an early warning system of infection and/or a measure of the extent of the infection. The lack of personal monitoring supplies or tests in a small community might preclude early warning through the CDC disease reporting system. Similarly, individuals who are asymptomatic might not choose personal (direct) testing, even if such testing were available. The SAB suggests that the EPA take into consideration the following factors for the wastewater testing efforts to be successful.

- The SARS-CoV-2 analytical test needs to be validated for wastewater matrices (including sample and storage).
- Half-life of the virus needs to be established.
- The impact of travel times to the sample collection point needs to be established.
- Virus shedding rates need to be established (e.g., Are these rates constant or variable depending on the stage of the disease?).
- The minimum infection rate needs to be established to begin observing viruses in the raw wastewater samples.

Furthermore, the SAB notes that there are potential logistical and economic issues, including the timely availability of information to react proactively, as listed below.

- Who will conduct and pay for the wastewater monitoring - sample collection, storage, preservation, analysis)?
- Will this be routine monitoring conducted by the NPDES permit holder?
- If the events are periodic or episodic, how will sampling programs be established to ensure infection in a community is observed?
- How long will it take for results to be posted? What is the time differential between infection and when virus shedding begins?
- If the sampling results takes two weeks to post, is it likely that the virus will be in and spreading through the community by the time the result is posted (i.e., well before anyone can react to the data)?

When conducting sampling for episodic events, the SAB recommends that the EPA consider partnering with the USGS. Their extensive experience with sampling of episodic events (i.e., storm events) will aid

the Agency with the logistics needed to adequately sample an episodic event, such as an outbreak, to ensure adequate data is collected to characterize the event.

2.6.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB agrees that inhalation of the virus is the main route of human exposure, which is a research area that could combine air and wastewater mediums (i.e., the aerosolization of wastewater during treatment or activated sludge). The SAB recommends that the EPA work with OSHA to ascertain the likelihood or prevalence of infection in wastewater treatment plant operators. Wastewater treatment plant operators have a high potential for exposure. A study of their health status could be a venue to gain information on whether the aerosolization processes used at these plants or any other aspect of the wastewater treatment process is of concern. Research on the antibody levels in wastewater treatment plant workers exists but it is historical (several decades old) and does not cover SARS-CoV-2. Data from this research could also be useful in the development of public education materials regarding aerosolized transmission among workers. The SAB provides two references for EPA's consideration (Mulloy, 2001; Thorn, 2001).

2.6.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term water/wastewater research questions and efforts. The uncertainties are known and have been identified as part of this review. The SAB recommends that the EPA research the following data gaps or areas:

- What uncertainties exist and what refinements are necessary to more accurately quantifying SARS-CoV-2 in the various water types (i.e., drinking water, wastewater, surface water, and groundwater)?
- How much infectious virus is excreted by an infected person and survives in water? Does the answer to this change based on how sick the person is or whether the excretion is saliva, urine or feces or any other measurable factor (age, immune status, nutritional status, etc.)?
- What is the survival of the virus deposited by human waste (saliva, urine or feces) in different waters (e.g., disinfected recreational waters, flowing natural waters, raw sewage, treated wastewater, and combined sewer overflows (CSOs))?

- What is the impact of wastewater flows and point of sample collection on ability to detect virus?
- Are there special concerns for Direct Potable Reuse (DPR) treatments? Is there evidence whether existing treatment for enveloped viruses is sufficient for removal or inactivation of SARS-CoV-2?
- What is SARS CoV-2 persistence in untreated water (i.e., sewage or wastewater before final disinfection, surface water, and groundwater)?

As EPA mentioned during their presentation on April 30, 2020, the Agency plans to evaluate the efficiency in which unit processes remove or inactivate the SARS-CoV-2 virus. The SAB believes that such data collection is critical to ensuring the treatment of drinking water and wastewater adequately protect public health. This data is needed immediately, and although the analytical methods for SARS-COVID-19 may be under development, the SAB recommends that the EPA work on developing a sampling program that can start immediately. The research should include a range of water quality conditions to ensure temporary changes do not impact the overall efficiency of the unit process. The SAB notes that this research is an appropriate and important use of the Agency's resources.

2.6.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate potential exposures from surface waters that might be contaminated from wastewater treatment plant discharges and/or other human activities. For example, beaches are closed every year due to contamination associated with human activities and EPA should assess whether current regulatory activities are protective in the context of SARS-CoV-2. The SAB notes that discharges from combined sewer overflows during heavy precipitation events should be evaluated. Although not directly intuitive, the SAB notes that the EPA should also reflect on some of the recommendations provided above as they relate to personal protective equipment, disinfection and transmission.

2.7. Air

Overall, the SAB recognizes this research category is critical to understand EPA's capabilities related to SARS-CoV-2. The SAB acknowledges that, although the Agency provided a high-level briefing and members have vast experience in this field of knowledge, the lack of specifics in some of the air research questions made them difficult to evaluate.

The SAB notes that there is a lack of a clear definition of the subject of various research questions or potential studies. This is often called a metric and it is specific to the scope of the study. The SAB strongly recommends that the EPA define the metric (e.g., a virus particle, a water droplet or the residual genomic RNA, among others). The metric may also be different depending on the study and how the specific research question is going to be applied in the evaluation process. In addition, the SAB has concerns about where and/or how the research questions posed by the Agency fit into the overall EPA's decision-making process.

The SAB notes that this research category is inextricably linked to various research categories, including *Environmental Exposure* (Section 2.5) and the *Environmental and Human Health Factors affecting transmission and severity of COVID-19* (Section 2.8) research categories, and encourages that the EPA regard the comments provided in this research category when considering those comments.

In the fields of either human or ecological risk assessment, a key step is the formulation of a conceptual model that clearly describes the bounds of a decision-making process. Also, the cause-effect processes that cover the origin and transmission of the pathogen in the environment, how exposure occurs to the population, and the occurrence of the disease are important. The SAB recommends that the EPA develop a conceptual model that reflects what is known about the cause-effect pathways and what is not known about SARS-CoV-2. When using a conceptual model, uncertainties could be identified as well as each cause-effect pathway and the variability in the probability distributions of each event. Many of the research questions and categories identified by EPA can address these pathways. A conceptual model, accompanied with a sensitivity analysis, could help EPA ascertain what the key steps are in the overall cause-effect process for COVID-19. This basic framing tool could add a degree of certainty to the overall research analysis.

The SAB recommends that the EPA use a matrix approach to define the range of environmental conditions in which to determine the persistence and exposure SARS-CoV-2. The axes can include variables such as temperature, humidity, air velocity, particulates (including their type and size), the size of the water droplets, the presence of disinfectants, types of HVAC systems, and so on. This matrix approach will help frame in detail the research conditions and aid the building of a quantitative risk assessment.

In addition, the SAB notes that there are several questions regarding particulate size and the rate of infection of the virus that should be addressed. It is well known that there are particles in a wide variety of sizes that could be deposited in a wide range of materials (including plastics, metals, organics, clays), a variety of aspect ratios, surface to volume ratios, density factors, among others. All particulate sizes are potentially important, given the variety of respiratory system areas (e.g., nose, throat, bronchi, bronchioles, and alveoli) that can be infected.

Lastly, while spaces, rooms and the outdoors can be modeled, exposure can also be measured directly. The SAB notes that personal monitors could be used among vulnerable populations to get an accurate level of their viral exposure, if/when appropriate. In addition to ambient air background levels, the personal cloud is critical in quantifying ‘true’ inhalation exposures. Also, an activity log could inform ventilation and/or inhalation rate estimates to attain exposure doses. The NIOSH is currently working on miniature sensors, which may open opportunities for bio-sampling.

The SAB believes that there are additional research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.7.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA’s mission and will have the most impact on EPA’s role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

Overall, the research questions are relevant to the understanding of SARS-CoV-2. As mentioned above, a reasonable cause-effect model would be useful to be able to make specific recommendations. The SAB notes that, in some instances, it is not clear where and/or how the research questions posed by the Agency fit into its decision-making process.

There are many potential partners, including the many components of the CDC, NIOSH, and others in the civilian governmental sector. Some of the potential partners have been identified previously in this document. As part of the U.S. Department of Defense (DOD), the U.S. Army Medical Research Institute of Infectious Diseases (U.S. AMRIID) at Ft. Detrick has had vast experience with infectious agents. Also, there is the U.S. Army Chemical Biological Center (U.S. CCDC) at Aberdeen Proving Ground, Maryland that has experience with a wide range of pathogens and biological materials. Lastly, a wide range of academic partners are also available from across the United States in schools of public health, engineering and environmental programs.

2.7.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

Short-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's short-term air research questions and efforts. All short-term research questions are important and should be addressed.

- How long does the virus remain viable in ambient air (as a function of temperature, humidity, UV, precipitation)?

The SAB recommends that the EPA collect this important information in a wide range of conditions to be able to calculate a viability-condition surface using systematic approaches.

- Can air vented outside from contaminated indoor environments carry significant infectious viral load outdoors, particularly in dense urban environments, or in cases of re-entrainment of exhausted air back indoors?

The SAB notes that this research question may be dependent on the type of housing (e.g., row houses, duplexes, condos, single family homes, density, among others) as well as the receiving outdoor environment or atmosphere and encourages EPA to consider these variables.

- Are there potential indoor sources that can contaminate areas or lead directly to exposure, through aerosolization (e.g., drain traps, toilet flushing, vacuuming, dusting, wiping, re-aerosolization from surfaces)?

The SAB agrees that there are potential indoor sources that can contaminate areas or lead directly to exposure through aerosolization. However, the type of source and the activity will determine the amount of aerosolization and the persistence in the environment. The SAB recommends that the EPA collect this information.

In terms of indoor ventilation, the SAB agrees that increasing the exchange rate with outdoor air (unless contraindicated), indoor airflow rates and patterns are areas that should be considered. Increasing airflow through filtration systems could decrease air contamination levels, but high flows can increase local contamination areas. Computational fluid dynamic (CFD) models are appropriate to visualize the airflow for a given room (e.g., a surgical room, emergency room, intensive care or recovery room, among others). However, other locations such as stadiums, gyms, theaters, convalescent homes, aircraft, buses, schools, could also benefit from such modeling approaches. The SAB suggests that this type of research begin in the near term improve on the current understanding of SARS-CoV-2, with the realization that this research area could continue long-term as an important area of study.

- Does SARS-CoV-2 remain viable after traveling through an HVAC system? How does the answer vary for different types of HVAC systems in different types of buildings or indoor environments (hospitals, large commercial buildings, residences, schools, airplanes, trains, buses)?

There are many types of HVAC systems for a variety of applications and it is difficult to generalize when a characterization of the various types of HVAC systems must be made. The SAB believes that this research question is one of the important axes for this research category and urges the EPA to quantify this information using a matrix-based study design.

Long-Term

The SAB has several recommendations and provides areas for consideration with respect to EPA's long-term air research questions and efforts. The SAB believes that some of the long-term air research efforts should begin in the very near term.

- If aerosol risks are excessive, how can aerosol exposure indoors be reduced?

The SAB notes that there are a variety of engineering and other tools that can be applied to reduce aerosol exposure indoors. The SAB recognizes that it is important to understand the factors (inputs) that could drive the results and produce unacceptable aerosol indoor risks. This information could be used to develop engineering alternatives or protocols to control those factors. The SAB recommends that the EPA set a clear goal using a risk assessment, informed by engineering equipment and/or behaviors, to achieve those goals.

- What precautions, if any, must be taken when cleaning or replacing different types of HVAC or portable air cleaner filters?

The SAB notes that precautions are needed when cleaning or replacing different types of HVAC or portable air cleaner filters. This research question should be informed by some of the short-term air research questions, as it is an extension of that work.

- Can airborne SARS-CoV-2 deposit in water bodies and lead to exposure via contaminated water?

The SAB recommends that the EPA begin researching this question now and continue the program long-term. Humans are exposed to water bodies thru a variety of activities, including walking through puddles on the sidewalk or playground. It is not clear what the persistence of the virus is in water bodies found in urban, suburban, industrial and rural areas. There are also a wide variety of aquatic environments with ranges of pH, nutrients, particulates, salinity, etc. SARS viruses can exist in a variety of species and different environments. The SAB urges the EPA to identify if this information is available for SARS-CoV-2. If not, then appropriate experiments should be designed.

- Does home vacuuming remove SARS-CoV-2 from the surface or cause it to aerosolize?

It is not clear if vacuuming removes or aerosolizes SARS-CoV-2. However, it is known that vacuuming can stir allergens and move them into the atmosphere, while it may also be removing some of the materials. This research question depends on the type of vacuuming system, how it is used, among other factors. The SAB recommends that the EPA include this question as part of the short-term research efforts with the long-term goal of controlling exposure.

2.7.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

As part of the short-term questions, the SAB agrees with the importance of this research and its inclusion into the Agency's timeline. As noted above, the SAB believes that some of the long-term research efforts should begin in the very near term.

2.7.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As noted previously, the SAB believes that there is a need for stronger and parameterized conceptual model(s) describing specifically how SARS-CoV-2 exists in the environment, spreads in indoor and outdoor environments, and the factors that cause its transmission. There are a few epidemiological models that provide general information on infection rates and mortality, but they are limited in terms of site-specification. Many of the research questions provided by EPA and discussed above, do not appear to be site specific. The SAB recommends that the EPA use its expertise in modeling site specific exposures to further define the research questions. The SAB also notes that the National Institute of Environmental Health Sciences (NIEHS) has experience in this area. The EPA could then use those models to help rank in a quantitative method or through a careful expert elicitation process the various research questions and set priorities.

2.8. Environmental and Human Health Factors affecting transmission and severity of COVID-19

This section provides the SAB recommendations for two research categories related to the transmission and severity of COVID-19.

As mentioned previously, the SAB finds that a conceptual model that describes causation and provides probabilistic estimates of exposure and risk would be beneficial to evaluate the importance and interconnectivity of the research areas. We note that for most risk assessment models, there are a few key variables that dominate the calculations, the uncertainty, or the decisions that must be made. The SAB encourages the Agency to ensure that results will be pertinent to specific exposure-effects pathways, as well as, accompanied by probabilistic descriptions and a careful consistent uncertainty and sensitivity assessment.

The SAB believes that there are additional research questions important for EPA to address. Some of the general questions are:

- What cause-effect pathway model is EPA assuming?
- Where do the specified areas of investigation fit into the larger framework?
- How will the Agency use the information produced by this research?

Specific recommendations are included in the responses to the charge questions and corresponding sections below.

2.8.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

The SAB finds that the research questions posed by EPA are well considered, relevant and clear. In improving this research category, the SAB believes that there is an opportunity for the Agency to clarify the nexus between the stated research questions and EPA's regulatory activities related to this work.

Although there is an overlap with other agencies (e.g., NIOSH, CDC, NIEHS and others), the SAB recommends that the EPA lead the development of these research questions to the extent permitted by their mandate and expertise. Also, the SAB notes that academic institutions and federal agencies that have ongoing research and/or expertise in the area of environmental exposures related to behavioral/socioeconomic characteristics will be important partners in this research category. The SAB recommends that the EPA work with these partners to identify: 1) how to gather various types of data (e.g., COVID-19 cases and death rates as they become available), and 2) how to evaluate the range of

potential factors affecting the transmission and severity of COVID-19. In addition, the SAB encourages EPA to identify if there a unique role in terms of occupational exposure (for healthcare workers, emergency responders, construction workers, fire fighters, police officers, among others) that should be addressed and to partner with NIOSH and OSHA.

In terms of exposures to air pollutants (e.g., Research Category 8, item #2 in the EPA document), the EPA can assess air pollution exposure concentrations from their monitoring networks in combination with land use regression models. In turn, this information can be integrated with case numbers as they become available from the CDC, along with other pertinent variables. The SAB believes that federal agencies should work together to determine who should conduct epidemiological analysis and how to bring all data streams together seamlessly. These efforts will ensure readiness to evaluate impacts prospectively (e.g., exposures from wildfires in the context SARS-CoV-2 in advance of the season). Furthermore, the SAB recommends that the EPA partner with organizations and/or academic institutions in estimating chronic exposure to air pollutants (e.g., particulate matter), along with other pertinent variables, in the context of responding to SARS-CoV-2 pandemic.

Lastly, the EPA in partnership with NIEHS, can help identify the best models for evaluating the built environment, including incorporating factors related to green space, socioeconomic characteristics, population density, and stress conditions (e.g., exposures to crime or criminal activities). National databases (many at a national-level or census-tract scale) are available, and many researchers have developed models for these inputs.

2.8.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several research questions recommendations and considerations that have the potential to refine or improve EPA's understanding and further support its role with respect to the pandemic.

- How are estimates of exposure expected to be impacted in specific states and cities, as restrictions ease in the phased re-opening plans? How do population density and mass transit use impact exposure?
- There is an opportunity for EPA to provide reassurance that compliance with existing regulations is sufficient and beneficial. Is the exposure to pollutants within or below current regulatory limits expected to increase SARS-CoV-2 transmission rates, exacerbate morbidity, or increase viral load susceptibility - as that would indicate a need to strengthen regulations?
- How are exposure factors related to living and working near construction sites, agricultural operations, and/or large operational manufacturing facilities which represent other sources of particulate in air, being considered in the context of SARS-CoV-2? To the extent that workers in these work settings, as well as those living close by, would face prolonged exposures to particulate in air, emissions, smoke and/or other lung irritants, do they also face a higher likelihood of contracting COVID-19, or evolve to be more severe cases, due to lung irritation?

- How exposure interactions related to the indoor/outdoor air interface? How the influence of temperature and humidity is being handled?
- How should lifestyle factors such as smoking and vaping (which are expected to affect lung function and the context of infection) be incorporated in exposure and risk models?
- What impact is expected related to exposure differences by age, given the interaction between age and living space layouts that interact with exposure factors (e.g., retirement communities, senior living, the use of handrails and elevators by the elderly, among others)?
- Given that the "personal cloud" (airborne materials in the breathing zone) adds to environmental ambient exposure, how should the effects of individual behavior be incorporated into models assessing inhalation exposure to the virus? For example, activities during work, play, sports, social gatherings, and other typical routines can place a person in close proximity to potentially infected individuals. These activities frequently increase breathing rates, with the effect of intensifying exposures above the level expected from passive exposures at low levels of exertion. In addition, intense exercise with oral inhalation can increase the rate of air intake by a factor of ten, bypass nasal collection, and thus increase aerosol deposition rates in the bronchial and alveolar airways.
- What is the impact of human health risk factors related to socio-economic status and its interaction with built environments, on SARS-CoV-2 virus transmission and risk? It is well established that how people recreate is also related to socioeconomic status or SES (e.g., common leisure activities, how individuals use water bodies, what kinds of playgrounds are commonly available (paved vs. grassed vs. gravel vs. sand), among others.
- Personal exposure monitoring and logging of coincident levels of exertion, are topics worthy of short-term research efforts, along with air quality monitors.
- Nutritional deficits should be considered as risk factors, as they could increase susceptibility to acquiring infections as well as hinder recovery. Short-term and long-term research questions on nutritional and other susceptibility factors, such life stage, genetics, stress reduction and routine exercise should be considered.

2.8.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB notes that all research questions related to these two research categories have been designated as long-term in the summary of EPA's current understanding and capabilities related to SARS-CoV-2. However, some research questions are better suited for short-term prioritization. Given that SARS-CoV-2 has been moving relatively quickly through susceptible populations, some of the long-term research questions posed by EPA could be useful in the short-term to provide critical and valid results.

In addition, the SAB recognizes that cities, counties and states are currently struggling to identify sports and/or recreational activities that the general population can participate in without increasing risk of disease transmission. The SAB believes that, taken as a whole, the eleven research categories described by EPA could provide useful insight to: 1) help jurisdictions make informed decisions about what activities to encourage versus discourage, and 2) ensure that SARS-CoV-2 transmission, morbidity and mortality are minimized.

2.8.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

2.9. Personal Protective Equipment (PPE)

Overall, the SAB finds that the short-term research questions and areas of focus identified by the Agency for personal protective equipment (PPE) are all important. Several points of clarification directly related to these questions have been provided in this document. The SAB believes that there are additional short-term and long-term research questions important for EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.9.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. *Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. *Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

The SAB finds that all the research questions for this category are clearly described and are well-suited to EPA's mission. The research questions in this category are well within EPA's capabilities and would benefit from their experience with such issues. The use of PPE is imperative to community protection in varied settings that range from occupational to the general community. Some tangible partners, likely in some combination include: the CDC, NIH and NIOSH. The agency may also consider partners in the private sector, in particular those in the manufacturing industry of PPE (e.g., 3M masks). There are many researchers in academia with expertise in nanotechnology and the social sciences that could be instrumental in the development of more efficient PPE and implementation of training and compliance programs, respectively.

2.9.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB provides additional questions and/or recommendations to be considered in EPA's current and future research initiatives, as listed below.

- There is not a clear understanding about live virus release from PPE over time, especially during PPE re-use, that would dictate how many times the materials can be used. The SAB recommends a consideration of this aspect when assessing PPE usage.

- The Agency should consider the following questions: Are viruses semi-volatile from PPE materials? Could they be a source of infection? Is the risk of infections different by demographics, including but not limited to, sex, race and age groups (adults vs children)?
- There are many options for disinfection, likely with a wide range of effectiveness. Disinfection is a function of exposure (CT, concentration x time). A range of disinfection options is possible with the same exposure concentration. For example, in terms of PPE, some concentrations will degrade masks faster than others (e.g., higher concentrations of an oxidant for a shorter time, versus a dilute oxidant for a longer time with the same CT). The SAB notes that the purpose in this area should be to minimize the degradation of the mask while achieving sufficient disinfection.
- Currently, available technologies to consider for disinfection include microwave radiation and silicon-based materials (e.g., those used in baking). Thermal disinfection at moderate temperatures for reuse of masks may be highly viable and easily controllable. The thermal disinfection curves (i.e., time and temp to achieve specific levels of inactivation) are well established for many common pathogens but would need to be validated for SARS-CoV-2. Use of chemical disinfection could be useful and should be studied, as each mask type from various manufacturers may be able to tolerate different levels of oxidative disinfection but fabrics may significantly degrade.
- The Agency should consider the use of contemporary technology to improve current state of PPE. For example, coating or impregnating PPE with nanomaterials known to have anti-viral activity (e.g., nano silver) might be more effective.
- The SAB recommends ensuring that new PPE re-use protocols and/or study designs in this area be easily implementable in various target settings and that they are designed with input training and compliance experts.
- Individuals changing out of their contaminated protective clothing (work clothes) to street clothes is notorious for producing excess exposures. Use of a personal monitor could be helpful in documenting inhalation exposures on an individual basis. Computational fluid dynamics modeling (or other methods) could be used in these changing areas (or stations) for the purpose of improving air flow patterns to decrease exposures from contaminated PPE.
- In most cases working with live SARS-COV-2 requires specialized biological safety level approval (BSL3). The Agency should consider the following questions: Do all studies need to be conducted/validated with viable SARS-CoV-2 or are surrogate viruses sufficient? If the latter, which viruses are good surrogates and could initial work be done with these candidates, followed by validation with SARS-CoV-2?
- When assessing PPE for safety, especially during re-use, the SAB believes it is important to identify the community, group or setting the Agency is trying to protect (e.g., healthcare settings versus occupational settings, schools, the general community). Also, the approaches will vary depending on the type of PPE used (e.g., surgical versus home-made masks).

2.9.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

While all research areas are important, the SAB suggests the following areas for long-term studies:

- Development of new and improved PPE technology (i.e. nanomaterials);
- Behavior studies to assess effectiveness of PPE programs based on compliance; and,
- Computational fluid dynamics modeling (or other methods) for the purpose of improving air flow patterns in high risk areas (i.e., changing areas/rooms for contaminated protective clothing or work clothes).

2.9.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

The SAB recommends that the EPA evaluate the following research components as relates to PPE disinfection, re-use and transmission of COVID-19.

- Assessment about how well the current PPE works during re-use in various settings;
- Development of improved PPE with the use of contemporary materials (i.e., nanomaterials);
- Modification of historical approaches to disinfection (e.g., heat, chemical);
- Considerations of PPE tailored to defined communities (i.e., health care setting versus schools versus general community); and,
- Re-use protocols for communities to implement and maintain high compliance.

2.10. Human Health Risks of Exposure to Disinfectants

The SAB believes that there are additional research questions important for the EPA to address. These questions are included in the responses to the charge questions. We also provide specific recommendations in corresponding sections below.

2.10.1. Charge Question 1

Within each research category, please discuss whether there is sufficient clarity to indicate how addressing a research question might inform Agency activities related to the SARS-CoV-2 pandemic? Specifically,

- a. Which research questions within a category are particularly suited to EPA's mission and will have the most impact on EPA's role in responding to the SARS-CoV-2 pandemic?*
- b. Are there research questions that could more effectively be addressed by another Federal partner, the private sector, academia or some combination?*

The SAB finds that the research questions for this category are well-suited to EPA's mission. The research questions in this category are well within the capabilities of the EPA and would benefit from their experience with such issues.

2.10.2. Charge Question 2

Within each research category, please identify if there are other research questions that have not been identified by the Agency, that have the potential to refine or improve our understanding and further support its role with respect to the pandemic.

The SAB has several recommendations and provides additional research questions/areas for consideration with respect to EPA's research efforts related to human health risks of exposure to disinfectants.

- In addition to children and individuals with respiratory sensitivity, are elderly individuals more sensitive to effects of disinfectants?
- Given that disinfectants can pose risks to children, are there scenarios under which application of disinfectants in daycare facilities could result in unacceptable risks?
- In addition to respiratory sensitization, will disinfectant also cause dermal sensitization?
- Will disinfectants, or compounds in disinfectant formulations such as terpenes, interact with ozone to form secondary pollutants? See reference Coleman, 2008.
- Are disinfectants stable or do they breakdown into more toxic or less toxic products?

- Considering that there may be many new individuals using disinfectants, including in both residential settings and public spaces, what are effective educational or outreach strategies for instructing users on safe application of disinfectants (e.g., users should ensure that air exchange rates are maximized during applications, opening windows, etc.)? The SAB notes that this is an area where the EPA could partner with the CDC.
- The scenarios listed in the EPA's Standard Operating Procedures (SOP) for Residential Pesticide Exposure Assessment focus on post-application exposures. What are exposures to residents that would occur during application of disinfectants (e.g., exposures from aerosolization of disinfectants)?
- Does EPA's List N for approved SARS-CoV-2 disinfectants account for potential of increased use and hence greater exposure? See Section 2.1 for additional considerations.
- What are exposures in more atypical scenarios, such as volatilization of disinfectant applied to automobile interiors, especially under conditions of elevated ambient temperature?
- As greater quantities of disinfectant are likely to be used by workers, and for longer periods of time, should additional PPE recommendations be made for workers? Specifically, should PPE protect for exposures to both the virus and the disinfectant? See Section 2.9 for additional considerations.
- To what extent workers applying disinfectants would have more prolonged exposures to higher levels of disinfectants that may cause lung irritation? Also, may workers be in demographic groups with a higher likelihood of contracting COVID-19? Would underlying lung irritation predispose individuals experience more severe forms of COVID-19?
- It is known that cleaning products can trigger asthma and/or asthma symptoms (Jaakkola, 2006). The SAB suggests that the EPA investigate relevant high-throughput assays to identify disinfectants that are not likely to trigger asthma/asthma symptoms. The SAB acknowledges that this area of research may be a long-term effort. In the meantime, the SAB recommends that the EPA provide guidance to organizations doing considerable cleaning work for workers and/or individuals with asthma to take additional PPE precautions.
- Electrostatic disinfection does appear to be increasing in use and it is a service offered by many professional cleaning companies. The SAB suggests that the EPA determine if this process leads to increased exposures and if PPE should be suggested when using this technique.

2.10.3. Charge Question 3

Within a research category, EPA roughly identified what research could be accomplished in the short-term, and what would be longer-term efforts. Within each research category, are there other considerations that might impact prioritization? How might research be prioritized across the landscape of research categories that have been identified?

The SAB finds that short-term research questions that could inform the extent of social distancing and ability to resume typical activities (e.g., such as going to work) should be prioritized both across and within categories. For questions identified as long-term, the SAB suggests that the EPA undertake a near term scoping exercise to define what is needed and whether there are aspects of the long-term efforts that can or should be undertaken in the nearer term. For example, the topic of exposure data for novel application techniques should be incorporated in the near term to identify what those techniques are. While it may be a long-term effort to obtain the desired data through EPA research, the SAB believes that the identification of the need as well as communication with relevant stakeholders, may provide additional approaches to obtain data. Similarly, the SAB notes that identifying options for addressing risks related to respiratory sensitivity could determine whether efforts should be short-term versus long-term in nature.

2.10.4. Charge Question 4

Are there any other important categories of research, focused on the Agency's role in responding to the SARS-CoV-2 pandemic, that are not captured in the existing table? If so, please discuss the current state of knowledge in the research category and identify what research would be relevant and inform EPA's efforts. Please provide some sense of prioritization and whether the effort is a short-or-long term research effort.

As mentioned in the charge questions above, the SAB has specific recommendations on how this research category could be strengthened to advance the Agency's capabilities and improve on the current understanding of SARS-CoV-2.

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